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A comparison of potential, active and post-active acid sulfate soils in Thailand

Tanabhatsakorn Sukitprapanon [a], Anchalee Suddhiprakarn [a,*], Irb Kheoruenromne [a], Somchai Anusontpornperm [a], Robert J. Gilkes [b]

[a] Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand
[b] School of Earth and Environment, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia

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ABSTRACT

Acid sulfate soils in Thailand have been modified by drainage, liming, irrigated agriculture and paddy rice growing over a long period of time generating potential (PASS), active (AASS) and post-active (PAASS) acid sulfate soils which have different soil properties and extents of soil development. This research compares Thai PASS, AASS and PAASS using field observations, mineralogy and chemical properties. Eighteen acid sulfate soil profiles, representing PASS, AASS and PAASS located in the Lower Central Plain and the Southeast Coast regions, were investigated. All three types of acid sulfate soils (ASS) contain a reduced layer below the water table. The soils are dominated by quartz, feldspars, kaolinite and illite with the Southeast Coast ASS being more sandy than the Lower Central Plain ASS. The labile minerals pyrite, jarosite, goethite, hematite, gypsum and halite are present in variously colored redox concentrations and have resulted from variations in drainage and oxidation status induced by land management including addition of lime. Mineralogical and geochemical properties of PASS, AASS and PAASS mostly reflect the nature of parent materials, but the ASS can be discriminated by the presence of labile minerals and by the labile chemical properties pH, sulfur content, organic carbon, electrical conductivity, actual acidity and total acidity. This research has clearly identified the labile properties that reflect the transformation from potential through active and into post-active acid sulfate soils. In addition, the transformation from PASS to fully oxidized PAASS is not a simple one direction oxidation process in ASS which have experienced cyclical freshwater-reflooding for rice cultivation.

1. Introduction

Acid sulfate soils (ASS) occupy approximately 17 million hectares (Andriesse and van Mensvoort, 2006) and are mostly situated in coastal plains in the Tropics and less commonly in temperate regions (Dent, 1986). ASS also occur in inland environments in lakes, wetlands and stream channels (Fitzpatrick and Shand, 2008).

Thai ASS have developed in Holocene sediments in the Lower Central Plain with small areas located in the Southeast Coast and Peninsular regions (Sinsakul, 2000; Land Development Department, 2006; Janjirawuttikul et al., 2010). Janjirawuttikul et al. (2010) reported that ASS were distributed in the deltaic plain which is occupied by tidal flats and swamp sediments deposited in the middle-late Holocene. The whole area was originally occupied by swamps with potential acid sulfate soils, but the area has been developed over one hundred and forty years under management that includes drainage, liming, irrigated agriculture and paddy rice growing (Attanandana and Vacharotayan, 1986) (Fig. 1).

Acid sulfate soils in other countries have also been drained, but the land uses are often different from those in Thailand. For example, ASS are drained in order to lower the water table for pasture and sugarcane in Australia and pasture in Finland (Tighe et al., 2005; Boman et al., 2010; Yvanes-Giuliani et al., 2014), for oil palm in Malaysia (Auxtero and Shamshuddin, 1991) and for construction and pasture in the United States (Ross et al., 1988; Fanning et al., 2004). In contrast, paddy rice growing involves reflooding of the reclaimed ASS every year which induces particular changes in ASS properties.

Under an undisturbed waterlogged anaerobic environment, soils affected by sulfidization and containing sulfide minerals near the soil surface are defined as potential acid sulfate soils (PASS) (Fanning, 2012). Pyrite is formed by the following reaction:

$$Fe_2O_3 + 4SO_4^{2-} + 8CH_2O + 1/2O_2 \rightarrow 2FeS_2 + 8HCO_3^{-} + 4H_2O \quad (1)$$

$$2FeS_2 + 15/2O_2 + 7H_2O \rightarrow 2Fe(OH)_3 + 8H^{+} + 4SO_4 \quad (2)$$

In general, iron sulfides in PASS comprise approximately 1–4% of dry weight (Gröger et al., 2011) and consist of pyrite (FeS_2), mackinawite

* Corresponding author.
E-mail address: agrals@ku.ac.th (A. Suddhiprakarn).

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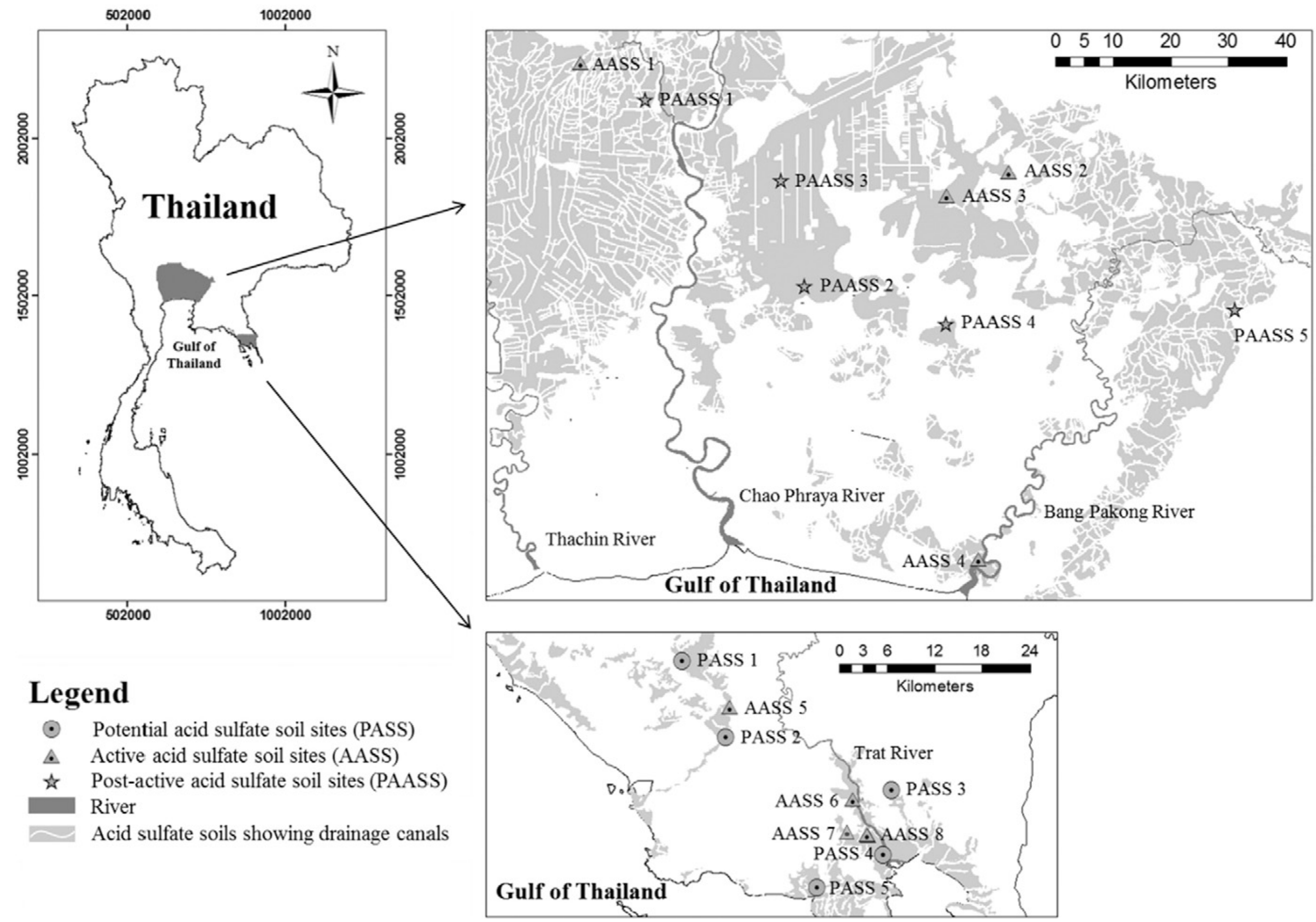

Fig. 1. Sampling locations for Thai acid sulfate soils in the Lower Central Plain and the Southeast Coast regions.

(FeS) and greigite (Fe_3S_4) (Fanning et al., 2010; Prakongkep et al., 2012) formed via reduction of iron oxides as a source of Fe (Eq. (1)) (Dent, 1986). Elemental sulfur may also be present (Burton et al., 2006a; Prakongkep et al., 2012). If these sulfur minerals are exposed to oxic conditions by natural or man-made drainage, sulfuric acid is produced (Eq. (2)) and soil pH will become ultralow (<4) where there is insufficient neutralization, creating active acid sulfate soils (AASS) (Fanning, 2012). This extreme acidity has adverse effects on agriculture, aquaculture and environment in ASS landscapes (Ljung et al., 2009; Sullivan et al., 2012). When weathering and pedogenesis in AASS have advanced to a stage where sulfide minerals are no longer present near the surface of the soil and where pH has risen above 4, which is commonly due to liming and drainage, the soils are described as post-active acid sulfate soils (PAASS) (Fanning, 2012).

At the time of sedimentation, PASS were uniform in their composition and properties. After PASS have experienced drainage, liming, fertilizers and paddy rice cultivation with periodic flooding they transform to AASS and eventually into PAASS which are considered as the mature stage. In the future, PAASS will become the dominant form of ASS in Thailand and elsewhere in the region due to the high productivity of these soils, particularly under irrigated agriculture. This publication identified changes in soil properties due to this particular management. Therefore, the research aim was to compare PASS, AASS and PAASS on the basis of field observations, mineralogical and chemical properties so as to identify affinities and differences among the three types of ASS.

2. Materials and methods

2.1. Soil sampling

Eighteen study sites were examined, these represent potential, active and post-active ASS in the Central Plain and the Southeast Coast regions of Thailand. The soils have developed under tropical savanna and tropical monsoon climates, respectively (Fig. 1). PASS for this study were collected from the Southeast Coast as it was impossible to collect PASS in the Lower Central Plain because fish and shrimp ponds and paddy rice have replaced the ASS formerly occupying mangrove swamps on the Lower Central Plain. Large areas adjacent to the Chao Phraya River now support extensive rice cultivation with much drainage and agricultural development occurring between 1870 and 1889 (Fig. 1) (Attanandana and Vacharotayan, 1986).

The PASS are waterlogged soils covered by swamp forest of mangrove and nipa (Table 1). The AASS and PAASS study sites have been drained for agricultural activities, particularly growth of paddy rice which involves several periods of flooding of soil profiles each year. The PAASS have been managed under this regime for more than a century whereas drainage of AASS has occurred more recently. Acid sulfate soils were collected in the dry season during October 2012 to January 2013. They were collect by hand auger to a depth of 2 m where reduced original sediments occurred in every case. The water table of AASS and PAASS was situated at approximately 80 to 100 cm depth.